BINAURAL AUDITORY BEATS AFFECT VIGILANCE PERFORMANCE & MOOD

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Reprint from Physiology & Behavior, Vol. 63, No. 2, pp. 249-252, 1998

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Received 18 July 1997; Accepted 29 August 1997

LANE, J. D., S. J. KASIAN, J. E. OWENS AND G. R. MARSH. Binaural auditory beats affect vigilance performance and mood. PHYSIOL BEHAV 63(2) 249 252, 1998. –

When two tones of slightly different frequency are presented separately to the left and right ears the listener perceives a single tone that varies in amplitude at a frequency equal to the frequency difference between the two tones, a perceptual phenomenon known as the binaural auditory beat. Anecdotal reports suggest that binaural auditory beats within the electroencephalograph frequency range can entrain EEG activity and may affect states of consciousness, although few scientific studies have been published. This study compared the effects of binaural auditory beats in the EEG beta and EEG theta/delta frequency ranges on mood and on performance of a vigilance task to investigate their effects on subjective and objective measures of arousal. Participants (n = 29) performed a 30-min visual vigilance task on three different days while listening to pink noise containing simple tones or binaural beats either in the beta range (16 and 24 Hz) or the theta/delta range (1.5 and 4 Hz). However, participants were kept blind to the presence of binaural beats to control expectation effects. Presentation of beta-frequency binaural beats yielded more correct target detections and fewer false alarms than presentation of theta/delta frequency binaural beats. In addition, the beta-frequency beats were associated with less negative mood. Results suggest that the presentation of binaural auditory beats can affect psychomotor performance and mood. This technology may have applications for the control of attention and arousal and the enhancement of human performance.

Keywords: binaural auditory beats, vigilance performance, mood, frequency-following response

WHEN two pure auditory signals of similar frequency are mixed together, the phase interference between their waveforms produces a composite signal with a frequency midway between the upper and lower frequencies and an amplitude modulation that occurs with a frequency equal to the difference between the two original frequencies. For example, mixing tones of 100 Hz and II 0 Hz yields a signal with a perceived frequency of 105 Hz that rises and falls in amplitude with a frequency of 10 Hz. The amplitude-modulated composite signal is called an auditory beat.

A similar phenomenon occurs when auditory signals of similar frequency are presented separately to the left and right ear through stereo headphones. Although each ear hears only one of the frequencies, the listener perceives the middle frequency and the amplitude modulation, even though the auditory beat does not exist in physical space. This phenomenon, called a "binaural auditory beat," and described more than 25 years ago (6), is created by the brain's processing of the two separate auditory signals at the level of the olivary nuclei of the brainstem.

Binaural auditory beats provide a mechanism for stimulating the auditory system at very low frequencies, below the frequency threshold of hearing. Such very low frequency auditory stimuli might be capable of eliciting an entrainment of EEG frequencies, similar to that known to occur during low frequency photic stimulation (photic-driving). Anecdotal evidence does suggest that presentation of low-frequency binaural auditory beats can elicit a variety of changes in the listener's state of consciousness that might have a broad range of practical applications (5,7). For example, the presentation of binaural auditory beats in the delta and theta frequency ranges is said to be associated with enhanced creativity and improved sleep. Preliminary experimental studies suggest that binaural auditory beats in the EEG beta frequency range can enhance attention and memory task performance (3), and that those in the alpha frequency range may increase alpha EEG production and subjective relaxation (2).

A recent study examined the effects of delta and theta frequency binaural auditory beats on EEG spectral patterns in healthy volunteers. EEG spectra were compared between a period of wakeful rest and a period in which participants listened through stereo headphones to pure tones designed to produce binaural beats in the theta and delta range. During the stimulus period participants produced significantly less spectral power in the alpha and beta EEG bands and significantly more power in the theta and delta bands, evidence of possible EEG entrainment by the binaural beat stimuli. During stimulation participants reported subjective experiences similar to meditative, trance, or hypnogogic states.

Taken together, the anecdotal, clinical, and preliminary experimental evidence suggests that the presentation of binaural auditory beats may produce controllable changes in EEG and/or

subjective states of consciousness. Only the most recent studies include sufficient experimental controls and can be considered as scientific investigations. Even so, the value of potential applications of a technology for self-control of EEG patterns and states of consciousness argues for continued investigation of the binaural beat phenomenon and its psychophysiological effects.

The present study was designed to investigate whether different patterns of binaural-beat stimulation could produce changes in level of arousal and alertness manifested in behavior and mood. A double-blind cross-over design was used to compare two distinct Patterns of binaural-beat signals, one containing binaural beats in the EEG-beta frequency range and the other binaural beats in the EEG-delta/theta range. These patterns were selected because these EEG frequency bands are typically associated with states of alertness versus drowsiness, and entrainment of these frequencies might thus enhance or impair alertness. The binaural-beat signals were presented continuously during the performance of a 30-min vigilance task that required continuous video monitoring and responses to infrequent targets. We predicted that presentation of binaural-beat signals in the EEG beta frequency range would elicit better task performance in this monotonous task (more correct detection of targets and fewer false alarms) than presentation of binaural beat signals that entrained EEG frequencies in the theta/ delta range. We also expected that differential stimulation would affect the mood changes associated with the monotonous task, especially those related to subjective alertness and fatigue.

MATERIALS AND METHODS

Subjects

Volunteers were recruited by advertisement from the Duke University community. They were required to be in good health, have normal hearing and vision (corrected or uncorrected), and be free from acute illness or use of medications. Thirty-two people were recruited and 29 completed the protocol. This group had a mean age (±SD) of 32 (± IO) years with a range from 19 to 51 years. The group contained 19 females and 10 males; 20 whites, 8 blacks, and 1 Asian; 18 employed workers and 11 students. All volunteers were nonsmokers. Each received $30 for completion of the study.

Materials

Binaural beat stimulation. Binaural beat signals were presented stereophonically by cassette tape. Three different tapes were prepared as follows. All three tapes contained a background of “pink noise” with uniform amplitude in the frequency spectrum from 40-320 Hz and decreasing amplitude (12 db/octave) at frequencies above and below these limits. Tapes also

contained carrier tones at 100, 200, 250, and 300 Hz, which had amplitudes 15 db above the amplitude of the pink noise. The tape constructed for the training session contained no binaural beat stimuli, but the tapes for the two experimental treatments did. For the delta/theta condition the 100-Hz tone was presented with a 1.5-Hz binaural beat, the 200 and 250 Hz tones were presented with 4-Hz binaural beats, and the 300-Hz tone was presented with no binaural beat.

Thus, this tape included binaural beats at 1.5 and 4 Hz. For the beta condition the 200-Hz tone was presented with a 16-Hz binaural beat and the 300-Hz tone was presented with a 24-Hz binaural beat. The 100 and 250-Hz tones were presented with no binaural beat. The tape for the beta condition contained binaural beats at 16 and 24 Hz. Subjectively the three tape recordings sounded exactly alike, described by subjects as similar to the constant monotonous roar of a waterfall or the sound inside a large propeller-driven airplane. The presence of binaural beats was very difficult to detect when the tapes were listened to by the experimenters, and none of the participants reported noticing them. The tapes were played to subjects through stereo headphones, and volume was set to a comfortable listening level.

Vigilance task A continuous performance vigilance task was administered using it personal computer (Compaq 386 SX), which contained a multifunction' data acquisition and timing card (ADAI 100; Real Time Devices, State College, PA) configured to measure response times with a precision of I ms. The vigilance task was administered using a special-purpose computer program written by J. D. L. It can be summarized as follows.

The participant watched the VGA video monitor as individual stimuli of 5-cm height were displayed at a rate of 1/s and a duration of 100 ms. The stimuli were capital letters that were selected at random from a list of 20 capitals that excluded those with similar shapes (e.g. 0 and Q). On 10% of stimulus presentations, the previous letter was repeated. This repetition of a stimulus was the target for the participant to detect. The computer program presented 1 target in each block of 10 stimuli (every 10-s interval) to insure that 6 targets were presented each minute, although the position of the target within the block was random. The intervals between targets ranged from 0 to 18 stimuli. The participant pressed the spacebar of the keyboard as quickly as possible each time a target was detected. The total duration of the vigilance task was 30 min. Instructions emphasized the importance of continuous monitoring for targets, rapid responding, and the importance of maintaining good performance throughout the entire task. The computer program administered all stimuli and recorded the parameters of each stimulus trial. Response latency was measured for all keypresses and recorded with stimulus data for later analysis.

Mood assessment. The Profile of Mood States (POMS; EDITS, San Diego, CA) was used to assess changes in mood. The POMS contains 65 adjective rating items (O to 4 scale) that

describe feelings people experience (e.g., friendly, tense, grouchy, etc.). Item ratings can be summarized on standard scales that represent six general moods: tension-anxiety; depression-dejection; anger-hostility; vigor-activity; fatigue-inertia; and confusion-bewilderment (4). This inventory was administered before and after the vigilance task to assess task-related changes in mood.

Procedure

Participants were kept blind to the true purpose of the study. When volunteers were recruited, they were told that the study was intended to evaluate a new computerized vigilance task and to assess how stable performance was over several days. Throughout the study, they were told that task conditions were identical across days and that the tape-recorded sounds were intended to provide a uniform monotonous auditory background that would blackout any external sounds. Participants were not told about the differences in the treatment conditions or the presence of auditory binaural beats on the tape recordings. This deception was judged to be necessary to prevent expectation bias regarding treatment effects. Furthermore, keeping participants unaware of the presence of binaural-beat stimulation prevented the distraction of actively listening to the tape recordings in order to determine their content, which could help to maintain arousal during the task and interfere with the development of a vigilance decrement. Use of this deception was approved by the Medical Center Institutional Review Board, and participants were debriefed at the conclusion of the study.

Each volunteer took part in three experimental sessions that were identical except for the treatment condition. Sessions were scheduled beginning between 1300 and 1600 hours, and all sessions for a participant were scheduled at the same time of day. Participants were asked to abstain from recreational drugs and alcohol for at least 24 h prior to testing and to get a normal night's sleep. Compliance was confirmed by self-report. The first experimental session was intended for training and to provide a stable level of performance for the two subsequent test sessions. The control tape recording, which contained the same sounds but no binaural beats, was presented during the training session. The beta and theta/delta treatment conditions were presented in the second and third sessions. The tape cassettes were blind-coded so that treatments were presented double-blind, and the order of treatments was counterbalanced across subjects.

Each session began with the completion of a short battery of questionnaires. The first session included completion of informed consent procedures followed by completion of demographic and health history forms. During the second and third sessions different psychological questionnaires were completed during this time. The POMS was completed at the end of this battery each day, immediately before the vigilance task, with instructions to describe feelings at that moment.

The computer program displayed instructions for the vigilance task on the monitor and presented samples of the stimuli. The experimenter reviewed the instructions with the participant, and the participant's questions were answered. Participants then completed a]-min practice/warm-up trial of the vigilance task, and performance feedback was provided upon completion. When the experimenter was convinced that the participant understood how to perform the task, the actual task was begun.

The participant performed the task while seated at a desk in a swivel chair. The room was dimly lit. The experimenter adjusted the stereo headphones and started the tape playback. Auditory volume was adjusted to a comfortable listening level for the participant that would block perception of external sounds. Then the experimenter left the room, and the participant began the 30-min vigilance task after a brief delay. The tape-recorded binaural-beat stimulation was presented continuously during the task. Immediately after completion of the task, the participant completed a second POMS to indicate how she or he felt at that moment. The experimenter reviewed a summary of performance to insure that instructions had been followed and reasonable levels of success obtained. However, participants received only general positive feedback each day.

RESULTS

Vigilance Performance

Task performance was scored as the number of correct target detections (out of a possible 180 targets) and the number of false alarms (when a keypress response was made to a nontarget stimulus). The number of hits and false alarms in the beta and theta/ delta binaural beat conditions were compared by paired t-test. Because we proposed a directional hypothesis, that beta frequency beats would improve performance compared to theta/delta frequency beats, a one-tailed test was used to maximize statistical power from our sample.

A total of 180 targets were presented during the 30-min task Participants detected a significantly larger number of targets when exposed to the beta-frequency binaural beats (mean = 153.5, SD = 23.6) than when exposed to theta/delta-frequency binaural beats (mean = 147.6, SD = 34.7). The difference in the number of correct detections was 5.9 ± 3.4 (mean — SEM), which yielded $t(28) = 1.7$ ($p < 0.05$). In contrast, participants produced more false alarms in the theta/delta condition (mean = 8.7, SD = 12.2) than in the beta condition (mean = 6.6, SD = 9.4). The difference in false alarms was 2.0 — 0.9 (mean ± SEM), which yielded $t(28) = 2.26$ ($p < 0.02$). Thus, the binaural beat treatments had the predicted effects on vigilance task performance.

To determine whether the treatments had differential effects on performance decrements during the vigilance task, performance scores for six 5-min periods were analyzed with a two-condition (beta versus theta/delta) by 6-period repeated-measures analysis of variance, using Greenhouse-Geisser corrections. The effect of period was significant for correct detections ($F(5, 135) = 7.63$, $p < 0.0008$), but the condition by period interaction was not ($F(5, 135) = 1.40$, $p < 0.24$); Although there was a significant decrement in correct detections over time during the task, the rate of decrement did not differ significantly between the beta and theta/delta conditions. For false alarms, neither the period effect or the interaction were significant (both $p > 0.20$).

Subjective Mood

POMS scale scores were evaluated by two condition X two period repeated-measures analysis of variance, in which the interaction tested the hypothesis that the binaural-beat stimuli would alter how the vigilance task affected mood. The main effect of period represented the effects of the vigilance task itself, regardless of treatment. We did not propose directional hypotheses for each of the six mood scales of the POMS, and thus used this omnibus approach to detect treatment effects.

As demonstrated by significant interactions, the binaural-beat condition affected scores for confusion/bewilderment ($F(l, 28) = 7.30$, $p < 0.01$) and fatigue/inertia ($F(l, 28) = 4.07$, $p < 0.05$), with a trend observed in scores for depression/dejection ($F(l, 28) = 3.81$, $p < 0.06$). Scores for confusion/bewilderment rose more from the beginning to the end of the vigilance task when the participant listened to theta/delta binaural beats (mean = 1.9, SE = 0.4, $p < 0.0001$), than when beta binaural beats were presented (mean = 0.9, SE = 0.4, $p < 0.03$). Moreover, scores for fatigue/inertia also rose more when the participant listened to theta/delta binaural beats (mean = 3.6, SE = 0.7, $p < 0.0001$), than when beta binaural beats were presented (mean = 2.3, SE = 0.8, $p < 0.005$). In contrast, depression/dejection scores rose slightly (mean = 0.3, SE = 0.2) when participants listened to the theta/delta binaural beats during the vigilance task and dropped slightly (mean = -0.4, SE = 0.4) when they listened to beta binaural beats.

Scores for vigor/activity did not contain a significant condition by period interaction, although there was a significant period effect ($F(l, 28) = 25.02$, $p < 0.0001$). Scores dropped from the beginning to the end of the task (mean = -2.9).

DISCUSSION

The results of this study provide evidence that presentation of simple binaural auditory beat stimuli during a 30-min vigilance task can affect both the task performance and the changes in

mood associated with the task. The observed effects were consistent with our predictions regarding differential effects on alertness and mood. Binaural beats in the beta EEG frequency range were associated with relative improvements in target detection and reduction in the number of false alarms compared to binaural beats in the theta/delta EEG frequency range. Moreover, beta binaural beats were associated with smaller increases in task-related confusion and fatigue compared to theta/delta beats, and the two conditions had different effects on scores for depression/dejection.

Scores on the confusion/bewilderment scale increased under both conditions, but rose significantly more during theta/delta frequency stimulation. This scale includes the items “confused,” I unable to concentrate,” “muddled,” “bewildered,” “efficient” (scored in reverse). “forgetful,” and “uncertain about things.” It appears to represent “a self-report of cognitive efficiency” (4). Changes observed in this study suggest that the theta/delta binaural beats produced a subjective impairment in the ability to think clearly. Performance of the vigilance task also increased scores for fatigue/inertia in both conditions, but more so for the theta/delta condition. This scale describes “a mood of weariness, inertia, and low energy level” (4) and includes “worn-out,” “listless,” “fatigued,” “exhausted,” “sluggish,” “weary,” and “bushed” as its items. The depression/dejection scale represents depressed mood accompanied by a sense of inadequacy, and includes “unhappy,” “sorry,” “sad,” “miserable,” “hopeless,” “unworthy,” “discouraged,” “desperate,” and “worthless” among its items. Together these scales suggest that the negative changes in mood produced by a monotonous task may have been partially ameliorated by the presentation of beta-frequency binaural beats.

These effects on behavior and mood were observed in the absence of participant expectations, and experimental controls ruled out other “placebo” effects. Not only were participants unaware of their treatment condition, they were unaware that different binaural-beat treatments were being presented during the three days of testing. Although experimenters knew the true nature of the study, they were careful to maintain the cover story throughout the study. Moreover, they were also blind to the order in which the experimental treatments were administered and thus could not systematically bias the results.

We presume that the behavioral and mood effects were mediated by changes in level of central nervous system arousal induced by binaural-beat stimulation. It is plausible that these signals entrained corresponding EEG frequencies and increased relative EEG spectral power in the beta or theta/delta bands. Such an interpretation is consistent with earlier studies that suggest apparent EEG changes in response to binaural beat stimulation (2), although the evidence of such effects remains preliminary. The present study lacked EEG measurements that could confirm this interpretation, but future studies can test this hypothesis directly.

It is interesting to note that similar changes in performance of a vigilance task were observed when normal volunteers were trained using biofeedback to increase or suppress EEG theta

activity (1). Those trained experimental groups did differ both in theta activity and in vigilance performance during testing, and suppression of theta activity during the task was associated with relatively better vigilance performance. Perhaps binaural-beat stimulation provides alternative means of suppressing theta activity, or enhancing beta Activity, to enhance performance. If so, it has the distinct advantage that it requires neither extensive training nor intent to self-control EEG for its successful application.

The observations in the present study have interesting implications. If binaural beat auditory stimulation can influence behavior and mood, then such stimulation may have useful applications for the self-control of arousal, attention, and performance. There may be potential applications of these performance enhancing signals in situations that demand high levels of continuous sustained attention and performance, such as commercial highway driving or air traffic control. Performance enhancing stimulation may prove useful in other occupational tasks as well. Conversely, binaural-beat stimulation that decreases arousal may have applications in the treatment of insomnia or stress.

The phenomenon of binaural auditory beat stimulation and its psychophysiological consequences deserves further study. Additional controlled studies will be required to determine what behavioral, affective, and cognitive effects different patterns of binaural beats might have and how any associated changes in physiology, behavior, or subjective experience might be used. Little is known about the mechanisms that may be involved in the transduction of simple auditory signals into changes in mood and performance demonstrated here. However, the results of this study demonstrate clearly that simple binaural-beat auditory stimulation can influence psychomotor and affective processes, even when people are unaware that such signals are being presented.

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